Implementation of a Faraday Mirror Stabilization Scheme for All Optical Switching in a Standard Telecom Fiber

C. Vinegoni, M. Wegmuller, N. Gisin

Group of Applied Physics, University of Geneva,
20 Ecole-de-Medecine, CH-1211 Geneve 4, Switzerland
phone: +41 (0)22 702 60 82, fax: +41 (0)22 781 09 80
e-mail: CLAUDIO.VINEGONI@PHYSICS.UNIGE.CH

We present an elegant passive stabilization method for ultrafast devices employing nonlinear polarization rotation (NPR) in optical fibers. The fluctuations in the linear birefringence, including temperature and pressure induced ones, that affect the measurement of the NPR are successfully removed in a passive way by using a double pass of the fiber under test with a Faraday mirror at the end of the fiber. This method provides excellent switching stability over long term period when applied to a wavelength converter.

The potential of nonlinear polarization rotation (NPR) to build ultrafast devices has been recognized a long time ago and received considerable attention since then. It has been proposed to exploit it for optical switches, logic gates, multiplexers, intensity discriminators, nonlinear filter, or pulse shapers. However, an inherent problem to all this applications is the stability of the output state of polarization, generally subjected to fluctuations of the linear birefringence caused by temperature changes and drafts in the fiber environment. Of course, the same problem was also encountered in the few experiments dealing with the characterization and measurement of the NPR itself.

As the fluctuations become worse for fibers with a large birefringence, and as the effect of NPR is proportional to the inverse of the wavelength, it is hard to measure NPR directly in a polarization maintaining (PM) fiber at the telecom wavelength of 1.55 μm. Consequently, NPR can not be exploited directly for an optical switch and some stabilization scheme has to be used. We propose a method that removes the overall linear birefringence, and therefore also its fluctuations, in a passive way by employing a Faraday mirror [1] (FM) and a double pass of the fiber under test.

The FM transforms any input polarization state to the orthogonal one upon reflection. Consequently, the signal components that were polarized parallel to one axis of the fiber during the forward propagation will be polarized parallel to the other axis during the return path and vice versa. The overall linear phase acquired is therefore the same for any input polarization, and the intrinsic birefringence is automatically

0-7803-6337-X/00/$10.00

removed as long as it is stable during a single go-and-return path. In this way, fluctuations with frequencies up to about 0.5 MHz (200 m long fiber) can be removed.

To check how this -nowadays standard- method [2] of removing linear birefringence acts on the NPR, we developed a simple model to calculate the action of linear and nonlinear birefringence. Using this model, one can show that the proposed method removes the overall linear birefringence only, whereas the purposefully induced nonlinear effects of the go and return-path add up. Excellent agreement between the model and some experiments we have made [2] about NPR demonstrates that using the FM, the overall linear birefringence is indeed removed completely, allowing to observe the NPR otherwise hidden within the noisy background of polarization changes due to environmental perturbations. This result validates our method for the implementation of an all optical switch based on NPR.

The principle of the optical Kerr switch presented here is based on NPR induced by a powerful control signal pulse that leads to a different phase-shift (via the optical Kerr effect) for signal components with the same and orthogonal polarization, respectively. The corresponding change in the output signal polarization (maximum angle of rotation) is maximized if the control signal polarization matches the polarization of one of the two signal polarization modes during the entire propagation in the Kerr fiber. By inserting a polarizing beam splitter (PBS), the signal is switched between the two PBS output ports depending on the amount of the induced phase-shift.

For the case of a PM fiber, when the control pulse is linearly polarized along one of the birefringent axis it is easy to show that the phase shift $\Delta\phi$ acquired by a signal linearly polarized at 45 deg is:

$$\Delta\phi = \frac{8}{3}\frac{L_{eff}}{\lambda} n_2 \frac{P}{A_{eff}} \qquad [1]$$

where n_2 is the nonlinear refractive index of the fiber, λ is the signal wavelength, A_{eff} is the effective area of the fiber and P is the peak pump power. Fiber losses are included in the effective length $L_{eff}= 1/\alpha[1-\exp(-\alpha L)]$ where L is the length and α the fiber loss coefficient. For a PBS adjusted so that all the signal is at output port 2 when the control pulse is absent, the signal at output port 1 becomes

$$T = \sin^2(\frac{\Delta\phi}{2}) \qquad [2]$$

where the induced phase shift $\Delta\phi$ is given by Eq.1. A different wavelength is conveniently used for the control pulses so that they can be combined with the signal using a wavelength division multiplexer (WDM). As a consequence, a walk-off between the control pulses and the signal is introduced, ultimately limiting the switching time. A large walk-off also enlarges the required control peak power because of a reduced interaction length (i.e. smaller L_{eff} in Eq.1). To keep the switch fast and efficient, either a fiber with low group dispersion has to be used, or the wavelength separation should be kept as small as possible.
It is very important to notice that the transmission given in Eq.2 holds only for a fixed intrinsic birefringence of the fiber. Any fluctuation of this birefringence, caused e.g. by temperature drifts or pressure changes, leads to an additional phase-shift randomly

changing the bias of the switch. In order to reduce this effect detrimental for the switch stability, different methods have been proposed.
Here we use the same stability scheme employed for the NPR measurements described above, i.e. a double pass of the fiber by means of a Faraday mirror.

The setup for the Kerr switch is shown in Fig. 1. The control signal and the control pulse are at 1559 and 1556 nm respectively. The experimental data for a 680 m standard telecom fiber are presented in Fig. 2. The output power at the switch is shown for a time period of several hours. After the initial setting the switch was left alone without any readjustment while a normal activity in the lab was maintained with people working around the table. The switch stability was rather good (less than 2% fluctuations) when using a FM. Instead when a normal mirror is employed, thereby removing our stabilization scheme, the output power at the switch port changes randomly from zero to full switch power.
The obtained switching ratio is shown in Fig 3 as a function of the control peak power. The maximum ratio corresponds to 90%. Similar data were obtained for a PM fiber 200 m long. In that case replacing the FM with a standard mirror leads to an output power rapidly changing in the range from zero to full switch power. Indeed it is well known that the polarization of light coupled into both the birefringence axis of a PM fiber is strongly susceptible to any perturbation and the use of a stabilization scheme is therefore absolutely mandatory. With a FM inserted, fluctuations of the switching stability were a little larger than 1%.

In conclusion we demonstrated all-optical switching at 1.5 μm, based on induced nonlinear polarization rotation in both a polarization maintaining and a standard telecom fiber. The presence of the FM at the end of the Kerr fiber removes any fluctuation of the signal providing good stability. In the standard fiber the switching was made possible because the small difference between the control and signal wavelengths allowed for a similar evolution of both signals along the fiber avoiding any scrambling along the fiber with a consequently reduction in the total amount of the NPR.

References

[1] MARTINELLI M., 'A universal compensator for polarization changes induced by birefringence on a retracing beam', *Opt. Comm.* 1989, 72, pp. 341–344

[2] VINEGONI C., WEGMULLER M., HUTTNER B., GISIN N. 'Measurement of nonlinear polarization rotation in a highly birefringent optical fiber using a Faraday mirror', *J. of Optics A*, Accepted.

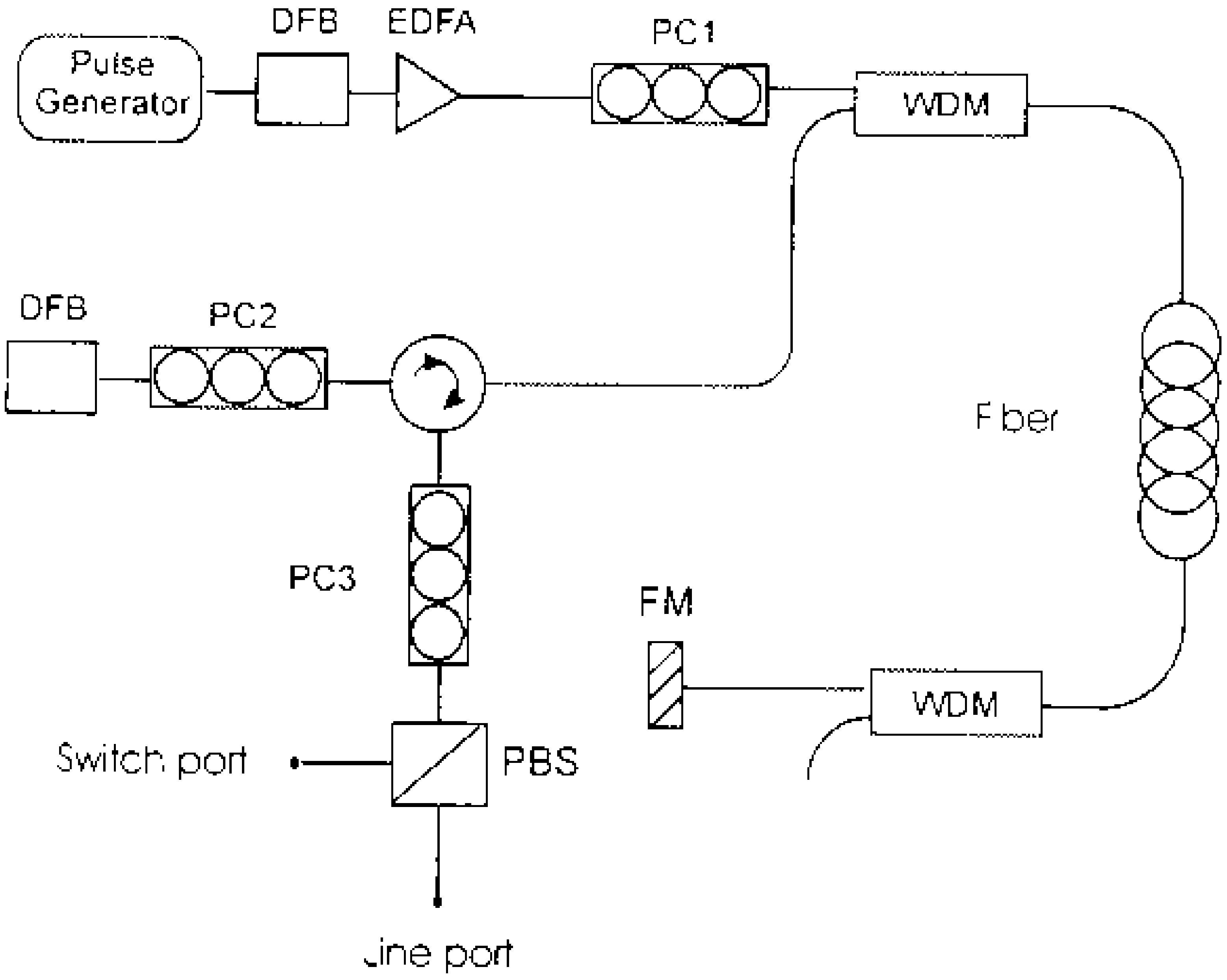

Figure 1: Experimental setup. DFB distributed feedback laser, EDFA Erbium doped fiber amplifier, PC polarization controller, FM Faraday mirror, PBS polarizing beam splitter, WDM wavelength division multiplexer

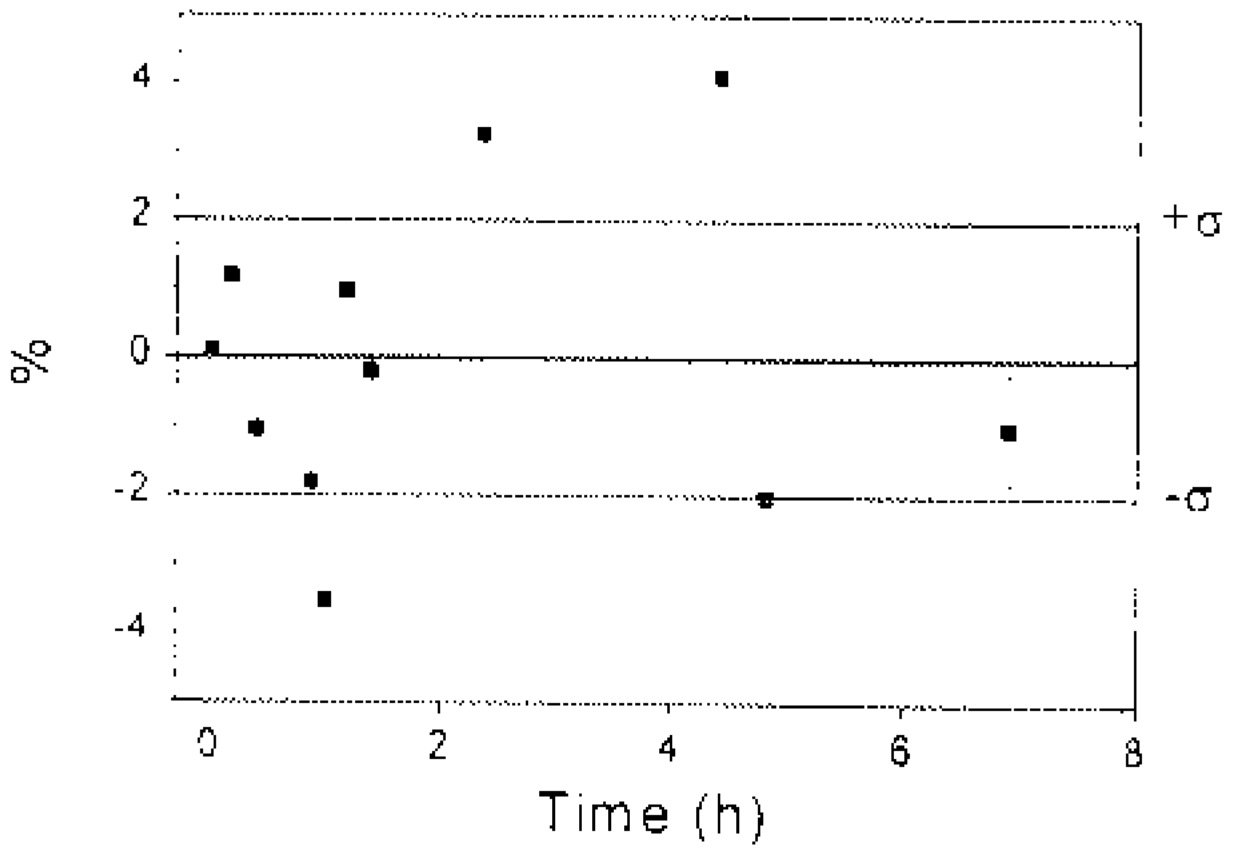

Figure 2: Relative fluctuations of the switch port signal power as a function of time. Measured data (squares), mean value (bold line), and standard deviation (thin lines).

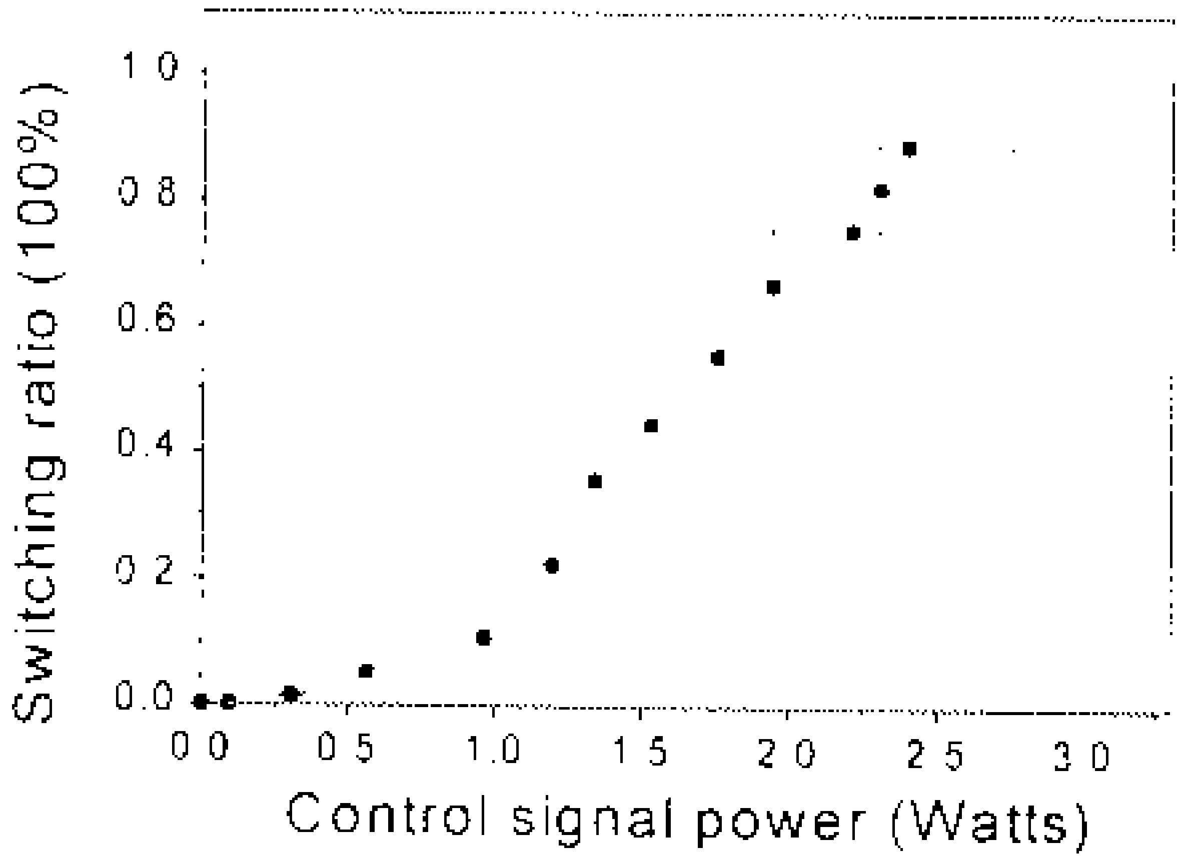

Figure 3: Normalized switching ratio as a function of the control signal power